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Abstract: Abstract This study determined the age and its changes across years of peak swimming performance from 50 to 1,500 m freestyle. Data of 70,059 Swiss freestyle swimmers (33,725 women and 36,334 men) aged 10-40 years and competing from 50 to 1,500 m were analysed. The association between age and swimming speed of the annual ten fastest swimmers was investigated using single and multi-level hierarchical regression analyses. For women, age of peak swimming speed increased in 50 m from 18.9 (s = 2.3) to 20.4 (s = 4.2) years but decreased in 1,500 m from 25.0 (s = 13.1) (1996) to 18.1 (s = 3.7) years. For 100-800 m, age remained at 19.1 (s = 1.1), 19.3 (s = 1.1), 18.7 (s = 1.5) and 18.5 (s = 1.3) years, respectively. For men, age of peak swimming speed decreased in 50 m from 23.0 (s = 4.0) to 23.0 (s = 3.5) but remained for 100-1,500 m at 22.5 (s = 1.4), 21.4 (s = 0.9), 20.3 (s = 0.9), 20.3 (s = 0.9) and 20.3 (s = 1.1) years, respectively. Age was positively associated with swimming speed for 50-800 m, but negatively for 1,500 m. In conclusion, the age of peak swimming speed was younger in women compared to men for 50-800 m freestyle. For women, age of peak swimming speed increased in 50 m but decreased in 1,500 m freestyle across years. For men, age of peak swimming speed decreased in 50 m freestyle.

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Peak swim speed in freestyle swimming

The changes in age of peak swim speed for elite male and female Swiss freestyle swimmers between 1994 and 2012

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Abstract

This study determined the age and its changes across years of peak swim performance from 50m to 1,500m freestyle. Data of 70,059 elite Swiss freestyle swimmers (33,725 women and 36,334 men) aged 10-40 years and competing from 50m to 1,500m were downloaded from the high score list of the Swiss Swimming Federation. The association between age and swim speed of the annual ten fastest swimmers was investigated using single and multi-level hierarchical regression analyses. For women, age of peak swim speed increased in 50m from 18.9 (*s*=2.3) to 20.4 (*s*=4.2) years but decreased in 1,500m from 25.0 (*s*=13.1) (1996) to 18.1 (*s*=3.7). For 100m-800m, age remained at 19.1 (*s*=1.1), 19.3 (*s*=1.1), 18.7 (*s*=1.5), and 18.5 (*s*=1.3) years, respectively. For men, age of peak swim speed decreased from 23.0 (*s*=4.0) to 23.0 (*s*=3.5) in 50m but remained for 100m-1,500m at 22.5 (*s*=1.4), 21.4 (*s*=0.9), 20.3 (*s*=0.9), 20.3 (*s*=0.9), and 20.3 (*s*=1.1) years, respectively. Age was positively associated with swim speed for 50m-800m, but negatively for 1,500m. Peak age was younger for women (~19 years) compared to men (~22 years) from 50m-800m. For 1,500m, women became younger than men over time. For 50m, women became older and men became younger.

Key words: swimming, freestyle, gender, age, performance

Introduction

Age has been reported as a performance influencing variable in endurance athletes (Leyk et al., 2007). In runners such as half-marathoners and marathoners, an age-related loss in endurance performance occurred after the age of 50 years. Mean marathon and half-marathon races times were practically the same for athletes in age groups 20-49 years (Leyk et al., 2007).

Generally, the age of peak athletic performance seemed to remain stable across years. Schulz and Curnow (1988) analyzed data of Olympic athletes from 1896 to 1980. They presented the age of peak performance of Olympic gold medal winners and showed that the age of the men's 100m dash from 1896 to 1980 remained relatively stable. However, there seemed to be differences for the age of peak running speed for different distances and sex. The age of peak performance seemed to increase with increasing length of an endurance performance. For runners, the age of peak performance for short-distance (Schulz & Curnow, 1988), middle-distance (Schulz & Curnow, 1988), half-marathon (Leyk et al., 2007), marathon (Leyk et al., 2007; Schulz & Curnow, 1988; Lepers & Cattagni, 2012), and ultra-marathon (Knechtle, Rüst, Rosemann, & Lepers, 2012a) running has been reported.

In marathoners, the age of peak performance was ~29 years (Hunter, Stevens, Magennis, Skelton, & Fauth, 2011) but increased to ~35 years in ultra-marathoners (Knechtle, Rüst, Rosemann, & Lepers, 2012a). In male long-distance triathletes competing in a Triple Iron ultra-triathlon, the age of peak performance was lower with 38.5 (s=3.3) years compared to Deca Iron ultra-triathletes with 41.3 (s=3.1) years (Knechtle, Rüst, Knechtle, Rosemann, & Lepers, 2012b).

The age of peak athletic performance seemed also to be different regarding the sex (Schulz and Curnow, 1988; Tanaka & Seals, 1997). Women generally achieved peak athletic performance at younger ages compared to men (Schulz & Curnow, 1988). The age of peak marathon running performance was younger for women with 29.8 (*s*=4.2) years compared to men with 28.9 (*s*=3.8) years (Hunter, Stevens, Magennis, Skelton, & Fauth, 2011). In ultra-marathon performance in a 100-km ultra-marathon, female winners with 33.2 (*s*=6.4) years were younger than male winners with 38.2 (*s*=4.5) years (Knechtle, Rüst, Rosemann, & Lepers, 2012a).

The age of peak endurance performance seemed to change over years. In Ironman triathletes competing in 'Ironman Hawaii', performance improved over time although athletes became older (Rüst, Knechtle, Rosemann, & Lepers, 2012; Gallmann, Knechtle, Rüst, Rosemann, & Lepers, 2013). In ultra-marathoners, the age of peak running speed increased over years in the 78-km mountain ultra-marathon 'Swiss Alpine' (Eichenberger, Knechtle, Rüst, Rosemann, Lepers, 2012b).

In swimmers, the age-related decline in performance was reported to be influenced by the swim distance and differed between women and men for short-distance pool-swimming (Donato et al., 2003; Schulz & Curnow, 1988; Tanaka & Seals, 1997). The age-related performance decline in freestyle swimming was greater in 1,500m than in 50m. For 50m, the age-related rate of decline was greater in women than in men (Donato et al., 2003). In women, the decline in swimming performance became progressively greater from 50m to 800m and 1,500m, respectively, whereas in men, no differences were observed in the performance decline between 100m and 1,500m (Tanaka & Seals, 1997).

The age of peak freestyle swim performance has been investigated for freestyle swimming for distances of 50m to 1,500m (Donato et al., 2003; Fairbrother, 2007; Schulz & Curnow, 1988; Tanaka & Seals, 1997). These studies showed different findings for the age of peak swim performance regarding the length of a swim distance (Berthelot et al., 2012; Eichenberger et al., 2012a). Recently, the age of peak swim performance was described at 21 years (Berthelot et al., 2012). The best 1,500m freestyle swimming times were achieved at a younger age of 18.4 years compared to the 50m at 23.1 years, respectively (Berthelot et al., 2012). However, Fairbrother (2007) reported that the age of peak swim performance for 50m freestyle was achieved at a higher age in men. In ultra-endurance swimming, peak swim performance was achieved between 30 and 39 years for both men and women (Eichenberger et al., 2012a). Considering the influence of sex, women achieved the fastest swim times in longer freestyle distances at younger ages (Schulz & Curnow, 1988). Tanaka and Seals (1997) reported that men reached their fastest swim times for 1,500m between 25 and 40 years whereas women achieved their fastest 1,500m swim times at the age of 30 to 35 years. In contrast, peak swim performance in 50m was attained at the age of 20 to 30 years in both women and men (Tanaka & Seals, 1997).

These conflicting findings might be explained by the age of the investigated swimmers. Some reports based upon rather old data from 1896-1980 (Schulz & Curnow, 1988), 1988-1999 (Donato et al., 2003), 1991-1995 (Tanaka & Seals, 1997) and 1993-2001 (Fairbrother, 2007), respectively. These studies missed to include the age group 10-19 years since Berthelot et al. (2012) reported that the fastest 1,500m swim times were achieved at ~18 years and Schulz and Curnow (1988) showed that the age of peak swim performance in women was at ~20 years or younger. Donato et al. (2003) investigated athletes aged from 19-85 years, Fairbrother (2007) from 19-96 years and Tanaka and Seals (1997) from 19-99 years. The studies of Donato et al. (2003), Fairbrother (2007) and Tanaka and Seals (1997) most probably missed to determine the correct age of peak freestyle performance since they excluded the swimmers of the age group 10-19 years from their analyses. Furthermore, anthropometric characteristics such as body mass and body height might have changed over time. Charles and Bejan (2009) reported that the fastest runners and swimmers were becoming not only faster but also heavier, taller and more slender across years. This fact might have influenced the results from Schulz and Curnow (1988) investigating swim performance from 1896 to 1980.

The data from Schulz and Curnow (1988) showed that the age of peak swim performance decreased across years from 1896 to 1980 and women were younger than men when they achieved their peak swim performance. However, newer data after 1980 are lacking and it would be interesting to investigate the trend in recent years. Also, Schulz and Curnow (1988) have not included the 200m freestyle for both genders and the 1,500m freestyle for women and the 800m freestyle for men in their analyses.

Therefore, the aims of the present study were to examine the changes in the age of peak freestyle swim performance from 50m to 1,500m for both elite female and male swimmers over time in recent years. Based upon present findings, we hypothesized that (*i*) the age of peak freestyle swim speed would decrease over time and (*ii*) women would be younger than men when achieving peak freestyle swim speed. To test these hypotheses, we analyzed the association between age and swim speed in elite female and male swimmers ranked in the annual top ten of the Swiss swimming high score list recorded by Swiss Swimming Federation. This database records since 1984 the top performances of all Swiss swimmers for all disciplines and distances.

Methods

Sample & Sources

The data set for this study was obtained from the website of the Swiss Swimming Federation (http://rankings.fsn.ch/). The Swiss Swimming Federation records in the Swiss swimming high score list the annual fastest race time for Swiss swimmers for all disciplines and distances. For freestyle swimming between 1984 and 2012, data were available from 71,102 swimmers, including 34,274 women and 36,828 men.

All procedures used in the study met the ethical standards of the Swiss Academy of Medical Sciences (www.samw.ch/en/Ethics/Guidelines/Currently-valid-guidelines.html) and were approved by the Institutional Review Board of Kanton St. Gallen, Switzerland (decision letter of June 1, 2010), with a waiver of the requirement for informed consent of the participants given the fact that the study involved the analysis of publicly available data.

Data Processing

All swim times of swimmers ranked in the Swiss swimming high score list between 1984 and 2012 competing in 50m pools were analysed regarding the association between age and sex with swim performance expressed in swim speed. No athlete was included twice or several times in the same year because the Swiss Swimming Federation lists only the annual fastest swim time of an athlete in the same year. The data base of Swiss Swimming Federation list the top ten and the top 100 female and male swimmers per discipline, distance and year. The data can directly be downloaded in an EXCEL file. From the EXCEL file, the data can be prepared for statistical analyses.

Due to the low annual number of swimmers per distance between 1984 and 1993, we decided to investigate only swimmers between 1994 and 2012, leading to a total number of 70,059 swimmers, including 33,725 women and 36,334 men. For each calendar year, the ten fastest women and men for 50m, 100m, 200m, 400m, 800m and 1,500m were sorted from the data base.

The change of both the age and the swim speed of the annual top ten freestyle swimmers was determined for distances of 50m, 100m, 200m, 400m, 800m, and 1,500m, respectively. Swim times were transformed to swim speed using the equation [swimming distance in meters] / [swimming time in seconds]. To compare swim speed between women and men, the sex difference in age and swim speed was calculated using the equation ([value (swim speed in m/s or age in years) in women] – [value (swim speed in m/s or age in years) in men]) / [value (swim speed in m/s or age in years) in men] × 100. Sex difference was calculated for every couple of equally placed athletes (*e.g.* between first woman and first man, between second woman and second man, etc.) before calculating mean value and standard deviation of all the pairings. Sex differences were transformed to absolute values before analysing.

Statistical Analysis

In order to increase the reliability of data analyses, each set of data was tested for normal distribution as well as for homogeneity of variances prior to statistical analyses. Normal distribution was tested using a D'Agostino and Pearson omnibus normality test and homogeneity of variances was tested using a Bartlet's test. To find significant changes in a variable across years, single regression analyses were used. Regression analyses were performed using the independent variable 'year' as a relative value related to the first year of analysis (1994 = 'year 0'; 2012 = 'year 18'). To account for potential clustering between time periods, a multi-level hierarchical regression analysis including athlete as cluster variable was performed. The structure of the multi-level hierarchical regression analysis was basically identical to a single regression analysis with an outcome variable (*i.e.* calendar year) and explaining variables (*i.e.* sex, age, and name of the athletes). The hierarchy resulted in the fact that some athletes were placed in the annual top ten for several years, *i.e.* repeated measurements at the level 'athlete'. The single outcome calculations where therefore not independent but clustered for the number of athletes with repeated places in the annual top ten. We calculated Intraclass Correlation Coefficients (ICCs) to estimate the variance that can be explained on the cluster level (*i.e.* race year, athlete). ICCs were calculated with variance of the year/total variance × 100. Statistical analyses were performed using IBM SPSS Statistics (Version 19, IBM SPSS, IL, USA) and GraphPad Prism (Version 5, GraphPad Software, CA, USA). Significance was accepted at $P<0.05$ (two-sided for t-tests). Data in the text are given as mean ± standard deviation (s).

Results

Change in age across years

Figures 1A to 6A show the change in the age of peak swim speed for the annual ten fastest women and men. For women, the age of peak swim speed increased in 50m from 18.9 (*s*=2.3) years in 1994 to 20.4 (*s*=4.2) years in 2012 and decreased in 1,500m from 25.0 (*s*=13.1) years in 1996 to 18.1 (*s*=3.7) years (Table 1). For 100m to 800m, the age of peak swim speed remained unchanged 19.1 (*s*=1.1) years, 19.3 (*s*=1.1) years, 18.7 (*s*=1.5) years, and 18.5 (*s*=1.3) years, respectively (Table 1). For men, the age of peak swim speed decreased from 23.0 (*s*=4.0) years in 1994 to 23.0 (*s*=3.5) years in 2012 for 50m but remained for 100m-1,500m at 22.5 (*s*=1.4) years, 21.4 (*s*=0.9) years, 20.3 (*s*=0.9) years, 20.3 (*s*=0.9) years, and 20.3 (*s*=1.1) years, respectively (Table 1).

Change in swim speed across years

Figures 1B to 6B show the change in peak swim speed for the annual ten fastest female and male swimmers. Swim speed increased in both women and men over time for all distances (Table 2).

Association between age and sex with swim speed

The multi-level hierarchical regression analysis (Table 3) showed for all distances between 50m and 1,500m a significant association between calendar year and swim speed for both women and men when corrected for age. Men were significant faster than women with a significant cluster effect (calendar year). Age was positively associated with swim speed for 50m to 800m, but negatively for 1,500m. All analyses were repeated with race year as quadratic term in the model to test a non-linear association between race year and swim speed. All regressions were linear.

Discussion

This study intended to examine the changes in the age of peak freestyle swim performance from 50m to 1,500m for both elite female and male swimmers at national level in recent years. It was hypothesized that the age of peak freestyle swim speed would decrease over time and women would be younger than men when achieving peak freestyle swim speed. The main findings were for women that the age of peak swim speed increased in 50m but decreased in 1,500m. For men, the age of peak swim speed decreased in 50m. For all other distances, the age of peak swim speed remained unchanged across years.

An important finding was that the multi-level hierarchical regression analysis showed that age was positively associated with swim speed for 50m to 800m, but negatively for 1,500m. This suggests that athletes would be faster at higher ages with the exception of 1,500m freestyle. A potential explanation could be the missing years of female participation between 1994 and 1996. The 1,500m freestyle were offered for women since 1996 in Switzerland, and entered in 2001 in Fukuoka (Japan) for the first time in the FINA World Championships in swimming (www.fina.org). Therefore, we performed a gender specific multi-level hierarchical regression analysis for 1,500m freestyle with inclusion of different race years (Table 4). For men, the significant association between age and peak swim speed remained significant for the calendar years. For women, however, the association between age and swim speed was significant for calendar years >2000 and >1993, but not for >1997 and >1995. The time frame of women competing in 1,500m freestyle seemed to influence the associations between ages and swim speed.

The present findings regarding the age of peak freestyle performance differ from those of Schulz and Curnow (1988). These authors reported for women that younger ages were associated with an increased swim speed with increasing swim distances. Indeed, these authors analyzed data of Olympic freestyle swimmers between 1896 and 1980 by investigating 100m, 400m and 1,500m for men and 100m, 400m and 800m for women, respectively. From 1896 to 1980, the age of peak swim performance was between 21.4 years for 100m and 20.3 years for 1,500m in men and between 19.4 years for 100m and 16 years for 800m for women, respectively. Schulz and Curnow (1988) separated their data into two halves (*i.e.* 1896-1936 and 1942-1980) using World War II as a dividing point. For men, the age of peak freestyle performance decreased across years in 100m from 22.0 years to 20.78 years, in 400m from 20.44 years to 19.44 years, and in 1,500m from 21.09 years to 19.44 years. For women, however, the age of peak freestyle performance increased across years in 100m from 18 years to 20.33 years, but decreased in 400m from18 years to 17.33 years. For 800m, there were no data available from 1986-1936 to compare with the second half after World War II.

The different findings between our data and the data from Schulz and Curnow (1988) might be explained by the different time frames investigated and the changes in anthropometric characteristics across years.While Schulz and Curnow (1988) analyzed data from 1896 to 1980, we analyzed data from 1994 to 2012. In swimming, anthropometric characteristics such as body height (Avlonitou, 1994; Geladas, Nassis, & Pavlicevic, 2005; Jagomägi & Jürimäe, 2005, Zampagni et al., 2008), age (Geladas, Nassis, & Pavlicevic, 2005; Zampagni et al., 2008) and grip strength (Geladas, Nassis, & Pavlicevic, 2005; Zampagni et al., 2008) have an influence on performance. Upper extremity length, horizontal jump, and grip strength were detected as significant predictors of 100m freestyle performance in boys. In girls, body height, upper extremity and hand length, shoulder flexibility, and horizontal jump were all significantly related to 100m freestyle time but the degree of association was markedly lower than in boys (Geladas, Nassis, & Pavlicevic, 2005). Age, body height, and hand grip strength were the best predictors in short-distance events, whereas only age and body height were predictors in middle- and long-distance events. Differences between genders were not found in 50m event, but were present in all other events (Zampagni et al., 2008). During the last century, changes in anthropometric characteristics occurred in the general population (Kagawa, et al., 2011; Krawczynski, Walkowiak, & Krzyzaniak, 2003; Marmo, Zambon, Morcillo and Guimarey; 2004; Simsek, Ulukol & Gulnar, 2005) and in elite athletes (Charles, & Bejan, 2009). Kagawa et al. (2011) analysed the changes in growth between 1900 and 2000 in Japanese children aged 6 to 17 years. Boys had body height and body weight increments of 1.0-2.0 cm per decade and 0.4-1.7 kg per decade whereas girls had rates of 1.1-1.9 cm and 0.4-1.5 kg per decade, respectively. The rates of body height increment were significantly different between pre-, during and post-World War II periods. While Japanese children were considerably taller in 2000 compared to 1900, height increments between 1950 and 1960 reflected a catch-up growth to restore physical size seen in children prior to World War II. The increments in body height continued after 1960 with greatest changes seen across the pubertal years. Simsek, Ulukol and Gulnar (2005) reported a significant secular increase from 1993 to 2003 in both body weight and body height measurements in 7-15-year-old boys and girls in Ankara, Turkey. Marmo, Zambon, Morcillo and Guimarey (2004) showed an increase in both body height and body weight between 1979/1980 and 1993/1994 for both boys and girls in São Paulo, Brazil. However, there seemed to be a levelling-off of both body height and body weight. Kurokawa et al. (2008) monitored the changes in growth among 6th year children in primary schools and 3rd year children in junior high schools in Sendai, Japan, since 1934. After World War II, both primary school children and junior high school students showed marked increases in both body height and body weight up to the early 1970s. Acceleration and the subsequent reduction in the degree of acceleration in growth were observed in 1965-1974 and 1975-1984, respectively, and were followed by reacceleration in 1985-1994. The period between 1994 and 1999 was characterized by positive trends both in body height and body weight among schoolchildren. However, the degree of the increases in both body height and body weight was diminished between 1999 and 2003. During the last century, there have also been changes in periods of increased and decreased intensity of acceleration of physical development. Krawczynski, Walkowiak and Krzyzaniak (2003) investigated changes in both body height and body weight in children and adolescents in Poznan, Poland, between 1880 and 2000. They reported periods of increased and decreased intensity of acceleration of physical development (*i.e.* the 1950s and 1970s, and the 1960s and 1980s, respectively), as well as a period of deceleration (*i.e.* the 1940s). In the last decade, the tendency has been towards deceleration in most age groups.

A further important finding was that the age of peak freestyle swim speed in the 50m distance increased in women but decreased for men. An explanation for this finding could be differences in body fat between women and men at this age. Body fat has been reported as a predictor variable for swimming performance (Siders, Lukaski, & Bolonchuk, 1993; Tuuri, Loftin, & Oescher, 2002; Zuniga et al., 2011). Siders, Lukaski and Bolonchuk (1993) reported that measurements of body composition such as body fat and body mass may be predictors of swimming performance in women but not in men. Tuuri, Loftin and Oescher (2002) showed that a greater fat mass in women was more strongly related to lower levels of performance. While the swimmers achieved their peak performance at ~20 years, specific changes in body composition at that age period might also be of importance. Bitar, Vernet, Coudert and Vermorel (2000) showed that during the onset of puberty, boys and girls gained fat-free mass, whereas fat mass gain was higher in girls than in boys. Lean body mass, which primarily reflects muscle mass, begins to increase during early puberty in both boys and girls. Fat mass, however, increases during the late stages of puberty in girls (Wheeler, 1991). A further increase in fat mass after puberty may impair swim performance in women. An important finding was reported by Stager, Robertshaw and Miescher (1984). These authors showed that the mean age at menarche was significantly later than controls (*i.e.* 13.4 years and 13 years, respectively). A later menarche means that puberty with the increase in fat mass will also be delayed. Stager, Robertshaw and Miescher (1984) assumed that the later menarche observed in swimmers appears to be associated with factors that select for superior performance. Zuniga et al. (2011) showed that boy and girl sprint swimmers at the age of ~11 years were different for percent body fat and suggested that the swim performance for girls may be improved through training programs designed to reduce body fatness. Furthermore, maturation is earlier in women than in men (Martin et al., 2011; Wheeler, 1991). This can be seen in bone growth during puberty in relation to physical growth (Magarey et al., 1999). Maximal increase of all bone variables occurred earlier in girls than in boys and earliest for bone width, then mineral content, then density. By age the age of 17 years, boys had attained 86% of the reference adult bone mineral content and volumetric density; girls had attained 93% of the reference adult bone mineral content and 94% of volumetric density. An actual study on growth of the metacarpal bones showed a difference of ~2 years in the growth pattern between body and girls (Martin et al., 2011).

Limitation, implications for future research and practical applications

This study has some limitations since anthropometric characteristics of the swimmers such as body mass, body height, body fat, skeletal muscle mass and grip strength were not determined. During the period 1994-2012, however, body mass might not have changed in elite Swiss swimmers since overweight and obesity has not increased in the Swiss population (Eichholzer, Bovey, Jordan, Schmid, & Stoffel-Kurt, 2010; Eichholzer, Bovey, Jordan, Probst-Hensch, & Stoffel-Kurt, 2010). The study missed also to analyse volume and intensity of the swimmers. Future studies need to investigate the changes in anthropometric characteristics over years in elite athletes at national level. Additionally, future studies need to confirm the present findings for swimmers at national level in swimmers at international level such as the FINA World Championships. Future studies need also to investigate the age of peak swim performance longer swim distances in the FINA World Open Water Swimming Championships over 5km, 10km and 25km. Implications of the present findings might show the importance that especially younger female swimmers should train and compete on the long freestyle distances of 800m and 1,500m. The age of peak swim speed is generally lower in women compared to men and decreased in the 1,500m and increased in 50m in women compared to men.

Conclusion

To summarize, peak age was younger for women (~19 years) compared to men (~22 years) from 50m to 800m. For 50m, women became older and men became younger across years. For 1,500m, women became younger across years. Differences in anthropometry between woman and men, changes in anthropometric characteristics such as body mass and body height over time and the shorter period for women (1996-2012) competing in 1,500m might explain these findings. Future studies need to investigate the effect of both anthropometric characteristics and training variables on swim performance in elite swimmers that might explain the improvement of swim performance without a change in age of peak swim speed. In addition, the present findings in swimmers at national level need confirmation in swimmers at international level such as the FINA World Championships or the Olympic Games.

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Distance (m)	Sex	Age (years)		r^2	F	*P*
		1994	**2012**			
50	Women	18.9 (*s*=2.3)	20.4 (*s*=4.2)	0.25	5.84	0.03 *
	Men	23.0 (*s*=4.0)	23.0 (*s*=3.5)	0.39	10.56	0.005 *
100	Women	19.1 (*s*=1.1)		0.14	2.8	0.11
	Men	22.5 (*s*=1.4)		0.04	0.72	0.40
200	Women	19.3 (*s*=1.1)		0.12	2.45	0.13
	Men	21.4 (*s*=0.9)		0.14	2.78	0.11
400	Women	18.7 (*s*=1.5)		0.17	3.54	0.07
	Men	20.3 (*s*=0.9)		0.13	2.4	0.13
800	Women	18.5 (*s*=1.3)		0.12	2.39	0.14
	Men	20.3 (*s*=0.9)		0.03	0.50	0.48
1,500	Women	25.0 (*s*=13.1) (1996)	18.1 (*s*=3.7)	0.47	10.64	0.007 *
	Men	20.3 (*s*=1.1)		0.06	1.1	0.30

Table 1: Changes in the age of peak swim speed over time. Women became older in 50m freestyle and younger in 1,500m freestyle; men became younger in 50m freestyle

Distance (m)	Sex	Swim speed (m/s)		r^2	F	*P*
		1994	**2012**			
50	Women	1.81 (*s*=0.02)	1.86 (*s*=0.01)	0.61	27.54	< 0.0001
	Men	2.04 (*s*=0.03)	2.15 (*s*=0.03)	0.78	63.80	< 0.0001
100	Women	1.68 (*s*=0.03)	1.72 (*s*=0.03)	0.56	22.07	0.0002
	Men	1.85 (*s*=0.02)	1.97 (*s*=0.03)	0.88	136.20	< 0.0001
200	Women	1.54 (*s*=0.02)	1.60 (*s*=0.02)	0.63	29.26	< 0.0001
	Men	1.69 (*s*=0.01)	1.78 (*s*=0.04)	0.90	167.7	< 0.0001
400	Women	1.47 (*s*=0.03)	1.52 (*s*=0.03)	0.29	6.98	0.017
	Men	1.59 (*s*=0.03)	1.68 (*s*=0.02)	0.75	51.39	< 0.0001
800	Women	1.41 (*s*=0.03)	1.48 (*s*=0.03)	0.36	9.57	0.007
	Men	1.49 (*s*=0.03)	1.57 (*s*=0.03)	0.75	52.68	< 0.0001
1,500	Women	1.14 (*s*=0.03) (1996)	1.42 (*s*=0.06)	0.48	11.20	0.006
	Men	1.48 (*s*=0.03)	1.54 (*s*=0.04)	0.75	52.78	< 0.0001

Table 2: Changes in peak swim speed over time for women and men

50m	β	SE	Z	*P*	95% Conf. Interval	
Year	0.0046	0.00048	9.59	< 0.0001	0.0036	0.0055
Age	0.0016	0.00058	2.73	0.006	0.00045	0.0027
Sex	0.24	0.0065	37.21	< 0.0001	0.23	0.25
ICC 49.5%				< 0.0001		
100m						
Year	0.0044	0.00040	11.02	< 0.0001	0.0036	0.0052
Age	0.0011	0.00053	2.15	0.031	0.00010	0.0022
Sex	0.21	0.0053	39.44	< 0.0001	0.20	0.22
ICC 45.2%				< 0.0001		
200m						
Year	0.0037	0.00036	10.11	< 0.0001	0.0029	0.0044
Age	0.00092	0.00049	1.87	0.061	-0.000043	0.0018
Sex	0.16	0.0047	34.53	< 0.0001	0.15	0.17
ICC 54.4%				< 0.0001		
400m						
Year	0.0028	0.00041	6.83	< 0.0001	0.0020	0.0036
Age	0.0028	0.00051	5.52	< 0.0001	0.0018	0.0038
Sex	0.12	0.0054	23.72	< 0.0001	0.11	0.13
ICC 57.0%				< 0.0001		
800m						
Year	0.0030	0.00045	6.77	< 0.0001	0.0021	0.0039
Age	0.0031	0.00053	5.89	< 0.0001	0.0021	0.0042
Sex	0.08	0.0057	15.0	< 0.0001	0.075	0.097
ICC 55.4%						
1,500m						
Year	0.0085	0.00082	10.35	< 0.0001	0.0068	0.010
Age	-0.0015	0.00077	-2.0	0.046	-0.0030	-0.000029
Sex	0.21	0.012	16.84	< 0.0001	0.18	0.24
ICC 88.1%						

Table 3: Results of the multi-level (hierarchical) regression analysis showing the effects of calendar year, age and sex on swim speed

Men	*ß*	SE	Z	*P*	95% Conf. Interval	
All years						
Year	0.0034	0.00056	6.03	< 0.0001	0.0023	0.0045
Age	0.0020	0.00069	3.02	0.003	0.00072	0.0034
> 2000						
Year	0.0023	0.00094	2.45	0.014	0.00046	0.0041
Age	0.0027	0.00089	3.03	0.002	0.00095	0.0044
> 1997						
Year	0.0034	0.00078	4.49	< 0.0001	0.0019	0.0050
Age	0.0022	0.00087	2.59	0.009	0.00055	0.0039
> 1995						
Year	0.0036	0.00064	5.66	< 0.0001	0.0024	0.0049
Age	0.0020	0.00074	2.70	0.007	0.00055	0.0034
> 1993						
Year	0.0034	0.00056	6.03	< 0.0001	0.0023	0.0045
Age	0.0020	0.00069	3.02	0.003	0.00073	0.0034

Women	*ß*	SE	Z	*P*	95% Conf. Interval	
All years						
Year	0.012	0.0013	8.91	< 0.0001	0.0094	0.014
Age	-0.0025	0.0011	-2.29	0.022	-0.0047	-0.00036
> 2000						
Year	0.0042	0.0018	2.27	0.023	0.00059	0.0079
Age	0.0063	0.0016	3.93	< 0.0001	0.0031	0.0094
> 1997						
Year	0.0091	0.0014	6.18	< 0.0001	0.0062	0.012
Age	0.0015	0.0011	1.31	0.189	-0.00077	0.0039
> 1995						
Year	0.011	0.0013	8.42	< 0.0001	0.0086	0.013
Age	-0.00064	0.0011	-0.57	0.571	-0.0028	0.0015
> 1993						
Year	0.012	0.0013	8.91	< 0.0001	0.0094	0.014
Age	-0.0025	0.0011	-2.29	0.022	-0.0047	-0.00036

Table 4: Results of the gender-specific multi-level (hierarchical) regression analyses for 1,500m freestyle with inclusion of different calendar years

Figure Captions

Figure 1 Age (Panel A) and swim speed (Panel B) of the annual top ten female and male swimmers in 50m freestyle

Figure 2 Age (Panel A) and swim speed (Panel B) of the annual top ten female and male swimmers in 100m freestyle

Figure 3 Age (Panel A) and swim speed (Panel B) of the annual top ten female and male swimmers in 200m freestyle

Figure 4 Age (Panel A) and swim speed (Panel B) of the annual top ten female and male swimmers in 400m freestyle

Figure 5 Age (Panel A) and swim speed (Panel B) of the annual top ten female and male swimmers in 800m freestyle

Figure 6 Age (Panel A) and swim speed (Panel B) of the annual top ten female and male swimmers in 1,500m freestyle

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6